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Learning to Attend to the Substance of Students' Thinking in Science

Abstract

In this paper, we explore how candidates in a graduate-level science teacher preparation cohort attended to the substance of student thinking while watching classroom videos or reviewing students' written work. We shared eight case samples of secondary science classroom work with the teacher candidates (six videos and two collections of student work), and asked them to discuss what they noticed in students' ideas and reasoning. We transcribed these conversations and coded candidates' comments in terms of what the candidates were attending to (e.g., student thinking, teachers' actions, student engagement). Our findings show that the teacher candidates were able to attend to specific student ideas and reasoning from the beginning of their pre-service preparation, but their practices of attending become more sophisticated over time. We discuss differences in the ways individual candidates participated and the ways in which participation dynamics within the cohort developed over time as participants assumed different roles and began to regulate their own discussions. We discuss the implications of this work for science teacher education.

Keywords: Science teacher education, attending, case study

Introduction

In the first week of an initial science pedagogy course in a secondary teacher education program, teacher candidates were watching a classroom video in which the students were trying to figure out the relationship between a species of owl and a species of blind snakes that were frequently found in the owls' nests. The students were discussing the possibility that the snakes served to clean the owls' nests by eating bugs that might damage the eggs, and they were presented with some data to explore this hypothesis. As the students looked at the data, one student noticed that most of the snakes were alive when the owl fledglings left the nest, but other snakes were dead. This student commented that the data suggested that the snakes were "either useful…or they're dead weight and [the owls] eat it." One of the candidates watching the video, Alex[1], had this to say about the student's comment:

> …[The student] is trying to immediately come up with a reason about why there are these two groups—why some snakes are alive and some snakes are dead and the reason that *they come up with, well some are good at burrowing and cleaning up the nest and some are bad at this job and so they're eaten by the owls. At least that's an interesting reaction to being told there's two groups and they immediately come up with some mechanism, some reason, some logical reason to explain why there are two groups, why there are alive and dead snakes.*

In his italicized comments here, Alex *attended to the substance* of the student's reasoning by identifying a student idea he thought was important, specifically interpreting the meaning of what the student was saying, and evaluating the student's thinking.

In this paper, we explore how Alex and the other members of his science teacher preparation cohort attended to the substance of student thinking while watching classroom videos or reviewing students' written work. Our findings demonstrate that the teacher candidates were able to attend to specific student ideas and reasoning from early on in their pre-service preparation, and their practices of attending improved over time. We also found differences among candidates that reveal how similar experiences in other contexts might help candidates attend to student thinking and help some to do it more quickly than others. These findings motivate us to consider how we should understand what it means to learn to attend to the substance of student thinking, an issue we take up in this paper.

The National Research Council (NRC) (2007) characterizes students' science learning across four strands, which correspond to: knowledge and use of conceptual content, reasoning abilities, epistemological understandings, and participation in scientific practices. In line with the NRC's conceptualization of science education reform, Atkin and Coffey (2003) and Hammer (1997) demonstrate how "proximal formative assessment" (Erickson, 2007), as it refers to teachers' ongoing, everyday attention to the substance of students' ideas, plays an important role in shaping teachers' instructional moves and supporting students' science learning across these strands. An important focus for science teacher education is thus to help pre-service science teaching candidates learn to attend to the substance of student thinking (Hammer & van Zee, 2006). Following work on teachers' "noticing" in mathematics education (Sherin & Han, 2004; van Es & Sherin, 2008),

[1] All names are pseudonyms

we take attending to the substance of student thinking as an important aspect of a "professional vision" (Goodwin, 1994) consistent with science education reform.

Professional vision refers to the way in which practitioners in any field "see the situation" in which they are working (Goodwin, 1994). However, current science teaching in schools is often not consistent with many of the goals of science education reform (NRC, 2007), and there is evidence that teachers' attention in the classroom is often diverted by systemic priorities that are not accountable to students' thinking nor to science (e.g., Rop, 2001). Teacher education must have a stronger voice in shaping teachers' professional vision—to support their abilities to "see the situation" in terms of students' ideas and reasoning.

There is a growing literature that explores what experienced teachers attend to and how to influence teachers' professional vision to align with reform expectations (e.g., Jacobs, Clement, Philipp, Schappelle, and Burke, 2007; van Es & Sherin, 2008), but few studies have been done with novice teachers (cf., Star & Strickland, 2008) and fewer still in science education. We document what happens in our science pedagogy program, which takes as a specific aim the development of teacher candidates' practices of attending to the substance of student thinking while examining records of classroom practice. We report results from the first two semesters in the science pedagogy course sequence, focusing our inquiry on three questions:

- What do our teacher candidates attend to when discussing records of classroom practice?
- How do practices of attending to student thinking develop over time within the cohort?
- Are there differences in how individual candidates attend to student thinking?

What Teachers Notice in Records of Classroom Practice: A Review of the Literature

We refer to practices of "attending" to student thinking, but our work is similar to a body of literature primarily in mathematics education that uses the term "noticing." The noticing literature is explicitly focused on the substance of student thinking, responding to reform documents in both mathematics and science education (NCTM, 2000; NRC, 2007) that call for teachers to "base their instruction on the lesson as it unfolds in the classroom, paying particular attention to the ideas that their students raise" (van Es & Sherin, 2008, p. 244). Several scholars (Hammer & Schifter, 2001; Jacobs et al., 2007) argue that professional development and teacher education aimed at focusing teachers' attention on the substance of student thinking is crucial for teacher learning; it is assumed that helping teachers notice students' ideas when exploring records of practice like classroom videos (e.g., van Es & Sherin, 2008) and samples of student work (e.g. Kazemi & Franke, 2004) will amplify teachers' tendencies to do so in their own classrooms. For the purposes of this paper, we are focusing on the teacher education setting, but we take up the issue of connections between teacher education and teachers' classroom practices in our discussion.

There is evidence that even experienced teachers initially have difficulty focusing on students' thinking in their content area when investigating records of practice such as videos, transcripts of classroom events, and student work (Hammer, 2000; Sandoval, Deneroff, & Franke, 2002; Sherin & Han, 2004). It may be, however, that teachers simply have very few opportunities to practice attending to student thinking. For example, in conversations with a group of physics teachers around records of practice, Hammer (2000) found that teachers' attention was frequently drawn to the actions of the teacher. He pointed out that comments about teacher action often served to convey implicit interpretations about student understanding. From this study, Hammer concluded that teachers have the ability to attend to student thinking, but they may not be accustomed to talking about student thinking, and they need practice.

Since attending to student thinking has not been a regular aspect of teachers' practices, professional development efforts in both science and mathematics education have sought to focus conversations about records of classroom practice around student thinking. Research has shown that these efforts, designed to help teachers get into the habit of attending to students' thinking and develop their abilities to hear and interpret students' ideas, have helped many teachers become more sophisticated in hearing and interpreting student thinking (Hammer & Schifter, 2001; Sherin & Han, 2004; van Es & Sherin, 2008).

There is little research on pre-service teachers' practices of attending to student thinking. Carter et al. (1988) suggest novice teachers' abilities to notice student thinking are poorer than experienced teachers' abilities. Theoretically, lacking any experience in classrooms, new teachers have more difficulty hearing and interpreting student ideas than experienced teachers do. However, in a more recent study in a pre-service secondary mathematics teacher education course, Star and Strickland (2008) found that teacher candidates generally did not enter the course with well-developed observation skills, but the course led to significant increases in these skills, particularly novice teachers' abilities to notice features of the classroom, mathematical content, and student thinking. Van Es and Sherin (2002) have also shown that pre-service teachers can learn to attend to student thinking fairly quickly. Our current study contributes to the noticing literature and literature on pre-service teacher education by exploring what happens in a pre-service science teacher pedagogy course sequence focused on attending to the substance of student thinking.

A Framework for Learning to Attend to the Substance of Students' Thinking

Drawing on the noticing literature, and based on our iterative coding for this project (see the section on data analysis), we describe in this section what we take as evidence of attending to the substance of student thinking. We also draw from other genres of literature, including physics education (diSessa, 1993; Hammer, Elby, Scherr, & Redish, 2005; Redish, 2004), cognitive science (Minsky, 1985), sociolinguistics (Goffman, 1974; Tannen, 1993), and anthropology (Lave & Wenger, 1991) to understand what it means to learn to attend to the substance of student thinking.

Attending to the substance of students' thinking.

Three aspects of attending to student thinking are prevalent in the noticing literature; we have identified these aspects in this study as well, and we consider them to provide varying degrees of evidence of attending to student thinking. These include: identifying students' ideas and reasoning, interpreting the meaning students are trying to convey, and evaluating the ideas and reasoning inferred from students.

Goodwin (1994) describes "highlighting" or identifying ideas as an important part of what practitioners in a field do. Identifying important ideas helps to "divide a domain of scrutiny in a figure and ground, so that events relevant to the activity of the moment stand out" (Goodwin, p. 610). We consider identifying important ideas to be a necessary precursor to attending to the substance of those ideas.

Once teachers identify important student ideas, Crespo (2000) distinguishes between teachers' comments that are evaluative and focused on correctness and those that are interpretive and focused on understanding. We believe that van Es and Sherin's (2008) definition of interpreting is closest to the meaning that we ascribe to the term. As van Es and Sherin state, "… we want to emphasize the importance of interpreting classroom events. Thus, how individuals reason about what they notice is as important as the particular events they notice" (p. 247). We speak of attending to the substance of student thinking in this strict sense – interpreting the meaning students are trying to convey, without simply evaluating the ideas. Thus, we take interpretive statements to be the best evidence that a teacher is attending to the *substance* of student thinking when discussing records of classroom practice. Furthermore, we believe that interpretive statements are the most productive in professional development contexts or teacher education courses – when teachers identify and interpret specific student ideas in collaboration with others, they have the opportunity to argue about their interpretations of the ideas, which leads to better-warranted evaluations and proposed instructional responses.

It is important to note that we view these aspects of attending to student thinking as analytical tools that help us make sense of how candidates are attending to students' ideas and reasoning. We are not making claims that these are separate cognitive processes within teachers' minds. Our purpose in describing these components is simply to examine those aspects of attending to student thinking that the candidates make explicit.

Learning to attend to the substance of students' thinking.

Our perspective for understanding how teachers learn to attend to the substance of student thinking draws from research on learning in physics (Redish, 2004; Rosenberg, Hammer, & Phelan, 2006). Hammer (2000b) argues that students do not draw on stable theories to reason in physics but rather that students employ small-grained, context-sensitive resources to do so. This framework builds on diSessa's (1993) description of phenomenological primitives or "p-prims," which are conceptual resources, based on learners' experiences with physical phenomena, which can be useful for learning physics. Hammer et al. (2005) have expanded the idea of resources to include fine-grained bits of declarative and procedural knowledge, metacognition, epistemology, and understandings of social norms that are derived from people's past experiences and activated in different situations.

Hammer et al. (2005) also suggest that in any moment, locally coherent sets of resources or framings are activated that are mutually consistent and reinforcing. Framing stems from a diverse history in cognitive science and sociolinguistics (Goffman, 1974; Minsky, 1985; Tannen, 1993). Here, we define framing as an individual or collective sense of "What is going on here?" Thus, framing involves an interaction between the contextual cues present in any given situation and the resources that various participants already have.

In any practice, which Wenger (1998) refers to as *sustained engagement in a joint enterprise using shared tools*, newcomers must learn relevant norms. Lave and Wenger (1991) describe the process by which newcomers learn these norms as "legitimate peripheral participation" (p. 29), which we take to mean that newcomers learn the framings of a particular practice through engaging and participating in that practice. We will argue that our teacher candidates draw on resources that they already have in order to participate in the practice of attending to student thinking. Additionally, by engaging and participating in this practice in various ways, the cohort establishes and reinforces a collective framing of attending to student thinking.

The language of framing has been used to understand how physics students frame what is going on in a particular context and how their framing is associated with their physics learning (Hammer et al., 2005; Redish, 2004); it has only been recently applied to secondary science pre-service teacher learning (Lau, 2010). Additionally, there has been little focus on how a framing of attending to student thinking is established and reinforced in a community of pre-service teachers. We return to our framework in our conclusion to articulate how pre-service secondary science teaching candidates learn to attend to student thinking while exploring case samples of classroom practice.

Research Context and Methods

Our data come from the first two courses of the three-course science pedagogy sequence in a one-year graduate-level initial teaching certification program at a large Eastern University in the United States. The course sequence is explicitly structured to draw teacher candidates' attention to the substance of student thinking, first by having them collectively examine records of classroom practice (videos and samples of student work), and then by having them collect and analyze such records from their own classrooms. During the first course (summer session), the teacher candidates identify frameworks for understanding students' science learning in the literature, interview students about science topics, engage in their own scientific inquiry, examine curricula for opportunities to draw out students' ideas and reasoning, and discuss samples of student thinking in classroom video and student work. The second pedagogy course (fall semester) continues these practices of examining and discussing samples of student thinking but goes beyond the first course in helping candidates develop instructional strategies consistent with science education reform and prepare to respond to student ideas as they arise during instruction. Candidates write lesson plans in which they anticipate what students might say or do and how they (as teachers) might respond instructionally. They then teach these lessons, collect student work or recordings of the class, and analyze the student thinking in evidence. In the third course, candidates collect data from their own teaching and write analyses of the student thinking in evidence. Here, we report on data from the first two pedagogy courses – specifically on how the teacher candidates attended to the substance of student thinking in records of classroom practice.

Research subjects.

This research was conducted as part of a larger effort to evaluate our pedagogy course sequence. As a result, the research subjects were chosen because they were enrolled in our graduate certification program. The first course in the sequence included thirteen pre-service secondary science teacher candidates. Six of these candidates were in a one-year program to earn a Masters degree and certification. Three were post-doctoral scientists pursuing certification only, and one was a former patent attorney with an undergraduate degree in physics, who was pursuing certification only. In the second course, three additional candidates joined who were participants in an integrated bachelors/Masters program for certification. All candidates had at least an undergraduate preparation in science content. In this paper, we consider the candidates as a group, and we also discuss differences in the ways that different candidates participated.

Procedures.

We shared eight sample cases of secondary science classroom work with the teacher candidates (see Table 1). Six samples were videos (each 20-45 minutes long) of secondary science classrooms with typed transcripts and/or captions. One of the videos was shown twice, as we discuss below. Two samples were collections of student work. We selected all of the samples from a collection developed as part of another project (Levin, 2008).

As the instructor, the first author (D) began the discussion of each sample by describing the context in which the work occurred or by having the group read the teacher's written description. We then shared the video or student work with the group, and D asked, "What do you notice in the students' ideas and reasoning?" D facilitated the discussion to draw specific attention to the substance of students' ideas and reasoning. For example, if candidates made a general statement such as, "It seems like the students get it," D would say, "Can you point to something someone said or did that makes you think they get it?" Similarly, if candidates directed attention to the action of the teacher by suggesting what the teacher should do or describing problems with the teacher's approach, D would ask what they saw in the students' reasoning that led them to make that claim about the teacher.

Data collection.

We videotaped the candidates' discussions of student thinking in each of the samples, which are summarized in Table 1. The discussions were each approximately 30-45 minutes in length. Due to

Table 1: Sample cases of classroom practice (in the order discussed)

Case sample	Description
Izzy's[2] "Owls and Snakes"	*Teacher and students discussing a biological phenomenon of an owl that shares its nest with blind snakes. Inquiry into symbiotic relationships, with students asked to consider evidence to support various hypothetical possibilities.*
Matt's "Galileo Worksheet"	*Student responses to a "tutorial" worksheet designed to draw on students' intuitive notions of inertia.*
Nicole's "Rime of the Ancient Mariner"	*Teacher and students discussing interpretations of the poem "Rime of the Ancient Mariner." Inquiry into osmosis, with students asked to construct mechanisms for the phenomenon of dehydration.*
Dan's "Owl Pellet"	*Teacher and students discussing the identity of a "Mystery Rock" (an owl pellet). Students asked to argue.*
Dave's "Galileo Worksheet"	*Discussion of the worksheet described above with a different teacher.*
Joe's "Egg Drop"	*Students' posters of their designs to produce a safe vehicle in which to drop an egg from a second story window.*
Joanna's "Curling"	*Discussion of what happens in the sport of curling, why participants "sweep" the ice, what it does, and how. Inquiry into friction and properties of water.*
Sarah's "Owls and Snakes"	*Similar to the discussion described above. Students explicitly asked to argue.*

the great variability among the samples, it was difficult to compare percentages of codes (see below) among samples in order to explore quantitatively how the cohort's practices of attending to the substance of student thinking changed over time by looking at the progression throughout the samples. Thus, we showed the sample we had shown at the beginning of the summer session again at the end of the fall semester in order to look at differences in how the candidates attended to the substance of student thinking in early and later discussions.

Data analysis.

To explore our first question ("What do our teacher candidates attend to when discussing records of classroom practice?"), we drew on a coding scheme to categorize each speech turn, which was developed by inductive coding (Miles & Huberman, 1994) in a similar project with practicing teachers (Levin, 2008). We then developed our codes further through an iterative process of coding a sample of the discussions, discussing our codes, and expanding or collapsing codes as appropriate. For example, the original coding scheme had only one category for attending to student thinking, which we recognized to be of two kinds: attention to specific student ideas and reasoning and attention to student thinking more generally. From this process we developed a scheme that organized what candidates attended to into eight categories: specific student thinking, general student thinking, the actions of the teacher, the nature of the activity, the science content, student attributes, student engagement, and "other" (See Table 2). A closer look at the "other" codes revealed that one third of these codes were simple statements in which candidates identified, or asked each other to identify, where on the transcript of the video (e.g., the line number) or which sample of student work they were referring to. Thus we created a new category, which we referred to as attention to the "tools." This coding was particularly important when we looked at how practices of attending to student thinking developed over time. D coded all of the transcripts. The second author coded one third of the transcripts, and we compared our coding to arrive at an inter-rater reliability of 83%. We then discussed each disagreement until we reached consensus on the remaining codes.

We also explored the diversity of ways in which candidates attended to student thinking via another round of iterative coding that focused only on the comments we had coded as attending to specific and general student thinking. We identified three different kinds of comments that were coded as attending to specific student thinking. At times, candidates 1) simply identified students' ideas, which we took as evidence that the candidates noticed the ideas, but we could not tell whether they attended to the meaning that the students were trying to convey. Candidates also 2) made evaluative statements in reference to students' ideas, which again indicated that the candidates were attending to the ideas that were present and perhaps making tacit interpretations of these ideas, but their interpretations (if present) were not made public. Finally, candidates sometimes 3) attempted to interpret what students were saying, which we took as the strongest evidence that they were attending to the substance of students' ideas. We did not take frequency counts of this coding because many utterances included overlapping codes at this level of analysis; instead, we considered how the three kinds of comments were related in candidates' statements. We explore the occurrences and relationships of these codes qualitatively in our analysis of the data.

To explore our second question ("How do practices of attending to student thinking develop over time within the cohort?"), we showed candidates the same sample case twice – once at the beginning of the summer session and again at the end of the fall semester. This sample (hereafter referred to as the "Owls and Snakes") showed a teacher and students discussing a strange relationship between a species of owl and a species of blind snake that lives in the owls' nests undisturbed. When we compared the initial coding of the first showing with the coding of the second showing, we concentrated primarily on the differences in attending to "specific" versus "general" student thinking and their relative changes over time. The discussions were slightly different in length, so we normalized the

Table 2: Coding what candidates attended to

Focus	Description	Example
Student thinking (specific)	Comments about specific student ideas or reasoning	*Maybe he's saying that they are practice for hunting—the snakes are just practice.*
Student thinking (general)	Comments about the general understanding or reasoning of students in the class	*I think most of them get it.*
Teacher action	Comments about something the teacher did or could do	*He could have kind of prompted it into like deeper discussion on other stuff.*
Activity	Comments about the activity, curriculum, or materials	*I think question 2 was kind of tricky.*
Science	Comments specifically about the scientific content	*Air resistance on the empty bottle has a similar effect as with feathers.*
Student attributes	Comments about students' abilities in general	*I don't think elementary students would understand that.*
Student engagement	Comments about students' interest or engagement	*They were paying attention.*
Tools	Comments that draw attention to the transcript or student work	*It's on page three.*
Other	Comments that do not fit in any of those categories	*Do you want me to address his question? Or…*

[2] The names of the case sample teachers are not pseudonyms as they have consented to having their real names used.

results by converting them to the frequency of codes uttered per 30 minutes of discussion. Both authors scored both transcripts completely, and we had 84% inter-rater agreement. Again, we resolved differences in coding by meeting and agreeing on the disputed codes. We also looked for patterns in the nature of the conversations and how participation in the norms and practices of attending to student thinking developed over time within the cohort. Specifically, we looked at who participated and how they did so over the course of the two semesters, how candidates drew each other's attention to specific student ideas and to the use of the tools, and how the role of the facilitator changed.

Results and Analysis

In this section, we present the results of our coding, followed by our analysis of the data and a discussion of the cohort's practices over time.

What candidates attended to.

We collected 995 coded passages over the course of nine discussions, including discussions of the eight samples plus the repeat of the first sample. We coded 43% of utterances as specific attention to student thinking, 6% as general attention to student thinking, 18% as attention to teacher action, 9% as attention to the activity, 11% as attention to science content, 3% as attention to student attributes, 1% as attention to student engagement, 2% as attention to the tools, and 3% as "other." (See Table 3)

Table 3: What candidates attended to

Focus	% of Total Codes
Student thinking (specific)	43
Student thinking (general)	6
Teacher action	18
Activity	9
Science	11
Student attributes	3
Student engagement	1
Tools	2
Other	4

As we discussed above, it was difficult to make any claims about quantitative changes in what candidates attended to from sample to sample because of differences in the content of the samples. To look at changes, we led a discussion of the same case sample at the end of the second course that we had discussed at the beginning of the first course and compared the changes in the frequencies of our coding. We only saw notable changes in the relative frequencies of attending to "specific" and "general" student thinking – the percentage of specific comments about student thinking (per 30 minutes) increased from 36% to 48%, while the percentage of general comments about student thinking decreased from 7% to 2%. (See Table 4)

These results suggest that our secondary science teacher candidates were able to attend to the substance of student thinking from the beginning of the pedagogy course sequence, when asked to do so. It might be argued that this is not surprising, considering that they were explicitly directed to attend to student thinking. Sherin and colleagues (2004; 2009), however, have shown that even experienced mathematics teachers struggle to attend to student thinking early on in professional development when directed in a similar manner, so our finding represents another perspective on the nascent abilities of teachers to direct their focus toward students.

We found that candidates routinely identified, interpreted, and evaluated students' ideas. At times, candidates made comments simply identifying a student's idea, and D followed up to ask what the candidates thought the student meant and what the candidates thought of the idea. Frequently, however, candidates specifically interpreted the student's meaning without prompting. These specific interpretations frequently led to sophisticated evaluations of students' conceptual understanding, reasoning, epistemological stances, and participation in scientific practices. Specific interpretations often occurred during long stretches of conversation that were about students' ideas and reasoning. For example, during an early discussion in which candidates were discussing whether the students understood the relationships among force, mass, and acceleration when considering gravitational motion, Sarah, who was often one of the quieter students, identified an idea on a student's worksheet that she did not understand:

> Sarah: "I was confused by what she meant about inertia canceling out, like for, on page 2, when they talked about how... and not falling at the same time because their inertia's different?"
>
> Jack: "Well again I think that just mass, or heavier mass is less acceleration because they were just going back to that and less mass is higher acceleration."
>
> Alex: "It's interesting because on question 3 she—at first the student states the right answer, they've got the concept that they land at the same time, and she understands that things that fall land at the same time, but then has trouble explaining why... she has this idea of the inertias canceling each other out, which indicates that she doesn't really have an understanding of what inertia is or how it applies in the case of falling objects."
>
> Jack: "Well again I think that goes back to their thinking the forces are the same, because she's saying 'the higher the mass the lower acceleration' versus 'a lower mass and a faster acceleration,' they are going to equal the same thing, so that's what she means, 'canceling out'—they're gonna equal the same thing."

Here, Alex offered an interpretation of the student's thinking that she "has this idea of the inertias canceling each other out" and evaluated that she "doesn't really have an understanding of what inertia is or how it applies in the case of falling objects." Jack interpreted the student's idea more specifically, suggesting why the student might be thinking about "canceling out," which had not been obvious to everyone. As the conversation

Table 4: How candidates attended to student thinking in Izzy's "Owls and Snakes"

Focus	Beginning of first pedagogy course (% per 30 minutes of discussion)	End of second pedagogy course (% per 30 minutes of discussion)
Student thinking (specific)	36	48
Student thinking (general)	7	2
Total	43	50

continued, Mark suggested another possible interpretation for what the student was thinking, and Elsa, Sarah, Ryan, and Alex debated Mark's interpretation, all drawing on the student's responses to other problems to debate what she might mean by "canceling out." This conversation about one specific student's thinking was followed by a discussion about how to teach the F = ma formula more generally, including how to help students recognize different situations (e.g. when acceleration is constant versus when force is constant).

Candidates often also made general comments about student thinking early in the first semester. In the first discussion of the "Owls and Snakes" sample, for example, we heard many general claims about what students understood or how they were reasoning. Candidates made declarative statements like "They were thinking out loud, and thinking logically;" "They're asking the right questions;" and "They're doing good stuff, they're reasoning, they're connecting their prior knowledge" without including interpretations of students' specific ideas to warrant their statements. These general comments are also evaluations, but they are evaluations of the student thinking in general, and not of specific ideas.

Candidates also made general comments about student thinking after long discussions of particular students' ideas. For example, in the "Owls and Snakes" sample, the teacher presents the students with some data, which leads to an interesting argument about whether or not the data fits students' hypothesized relationship between the owls and snakes. During the first viewing of the sample, candidates had a long discussion about particular students' ideas during this segment (including a number of comments we coded as "specific" student thinking), at the end of which Ryan made the following general claim:

> "I can see the students are, uh, doing something that I agree with, which is not assuming that just because there's data that indicates something, that that means that [the owls and snakes are] getting something out of it."

Here, we see an example of a general statement about student thinking, which is an evaluation that the students are doing something with which Ryan agrees. It differs from the other general statements above in that, following a conversation about specific student ideas and reasoning, it is likely grounded in the interpretations that candidates provided during the preceding conversation. Ryan was able to specify what he liked about the students' arguments – the students did not assume that the data supported a particular answer.

When we looked at candidates' general comments in the second discussion of the "Owls and Snakes" sample, we found that there were fewer general comments relative to specific comments. Also, the general comments were all of the kind that followed interpretations of specific student ideas and reasoning; none were the blanket evaluations we had seen in the first discussion (e.g., "They were thinking out loud, and thinking logically"). For example, the group discussed a student's comment about how some data they were shown supported a claim of a particular hypothesized relationship:

> Mark: He's saying that the snakes helped somehow; helped the owls somehow.
>
> Suzanne: So I mean isn't he getting at mutualism because snakes are helping? They're having increased growth rate and they owls are having increased growth rate. And the snakes are surviving also so isn't that kind of what he's thinking over?
>
> Jack: I mean this whole time do none of the students assume that like since they're—the snakes are eating bugs and they have food then that's like something that's helping the snakes out or... because I think that's just one point that would like solidify mutualism because they're really only looking for whether the snakes help the owls but the snakes are eating—I mean I think that's a positive.

In this exchange, Mark and Suzanne made specific interpretations about a student's idea, and Jack followed up on their interpretations to point out something that he saw in general—that the other students *had not* been talking about how the relationship was beneficial to the snakes—to support the overall positive evaluation of the student's new idea. This kind of general claim about student thinking draws on specific interpretations of students' ideas and reasoning and can therefore provide novel and productive warrants for the evaluation of student thinking.

How practices of attending to students' thinking developed.

In addition to exploring the content of what candidates attended to, we looked at how their participation in the conversations changed over time. In the earliest discussions, all of the candidates spoke, but some participated more than others. These included Alex (the patent attorney) and Elsa (a post-doctoral scientist), but others, particularly Jack and Ryan, also participated considerably. Alex in particular seemed to understand that the central aspect of the practice of attending to student thinking was to make claims about students' meaning by identifying specific things that students said. As we discussed above, D actively modeled this practice by asking candidates

for specific examples. In the exchange below from the first "Owls and Snakes" discussion, we see Alex jumping in with an example even before D has finished asking for it:

Ryan: "I thought it was a really impressive class."

D: "Say more about that, why?"

Ryan: "Because, uh, they were thinking out loud, and thinking logically, and the teacher was doing a great job of getting them to use reasoning."

D: "So let's see if we can find –" (overlapping with Alex)

Alex: (overlapping) "I like that distinction of that there's the good, the good maid and the bad maid, because the students are told there's a distinction, right, some snakes are eaten and some snakes aren't, there's eighty-nine percent that are alive and eleven percent that are dead, although they're not really told that they're eaten. Only one seems to be half eaten. So they're trying to immediately come up with a reason about why there are these two groups, why some snakes are alive and some snakes are dead and the reason that they come up with, well some are good at burrowing and cleaning up the nest and some are bad at this job and so they're eaten by the owls. At least that's an interesting reaction to being told there's two groups and they immediately come up with some mechanism, some reason, some logical reason to explain why there are two groups, why there are alive and dead snakes."

Although Alex and some others dominated the conversations at the beginning, others began to participate within the first few discussions. D often stepped in to openly encourage participation by others and to maintain a focus on conversations that went beyond evaluations of correctness or incorrectness. In one classroom video candidates watched, the teacher and students discussed the meaning of Samuel Taylor Coleridge's poem, "The Rime of the Ancient Mariner," after learning about diffusion and osmosis. The transcript of candidates discussing the video follows the poem.

Water, water everywhere, and all
the boards did shrink

Water, water everywhere, nor any
drop to drink

D: "So what do you notice in, uh, what the students are saying, in their ideas and their reasoning about this problem?"

Alex: "Well, some students, like in line 9, are just immediately jumping to the terminology they just heard, you know, the teacher's like, 'Do you guys have any ideas?' and students 1 & 2 say 'Hypertonic!' at the same time, sort of as if that's the answer. They, they don't say, they're prompted to say more than that as if they, uh, don't know that that's the incomplete answer."

Jonaki: "And they'll also kind of say, like, you lose water, like once you lose water from your cells, you die, but they just can't relate to, like, okay dehydration, what happens? They know what is dehydration, but they can't relate it to the cells, like what's happening, physiological phenomenon inside your body."

D: "Yeah, so you've, uh, you've probably seen that come up a couple times –"

Jonaki: "Uh-huh."

D: "So there's sort of a focus on vocabulary, and then this difficulty of sort of explaining themselves or elaborating. Um, what about, uh, other stuff?"

Alex: "Uh, there was –"

Anita: "Oh, I like how, um, I guess starting on line, like, 45, when he starts talking about how, like, what happened in his basement. He's trying to, like, use all his prior knowledge to try to apply it to the question that she's asking."

Maria: "A positive thing I noticed, um, was they understood that wood absorbs the water. Like that was very visual for them because then they, in 170, they relate that to the plant and, like, a tree, and how the tree absorbs water."

Alex began the conversation by pointing out that students were simply repeating vocabulary they had heard. Jonaki pointed out that students were missing the details of the "physiological phenomenon." D prompted for other ideas, and Anita, interrupting Alex, identified a specific student's idea and suggested that it was evidence of the student drawing on his prior knowledge. Maria brought up a similar instance in which students drew on their background knowledge of water and trees. We see this snippet as evidence that even students who spoke very little, like Jonaki, Anita, and Maria, were starting to feel comfortable participating and using the transcript as a tool to identify important student ideas.

By the second viewing of the "Owls and Snakes" sample in the second pedagogy course, multiple candidates were participating in long conversations about student thinking without prompting from D. For example, Jack brought attention to a situation in the video in which a student, responding to a question from the teacher, said that a particular piece of data could be "used to evaluate" the students' hypotheses about the relationship between the owls and snakes. Jack thought that the student was just choosing one of the options the teacher had given him (can or cannot be used to evaluate the hypotheses) without thinking about it. Other candidates were not so sure. When the teacher asked the student, "What does it add that will help us answer the question?" the student replied:

"Uh, it could enter the nest on its own. The snakes are capable of climb, climbing up trees, and they can get to the nests on their own… and, if owls and snakes ever turn against each other, they could use that as an advantage for like, uhhh, battle and stuff."

Kay: "He's saying that the snakes are making the choice to go there. Like I…"

Mark: "Right, that's what I read here."

Kay: "Right, and then that's what's important about it to him…"

Jack: "Right, so right. I see where that is important but I don't know if [he] understands that… he says, 'Yeah, they can climb trees'… but then line 23 I don't understand what he was meaning there because [he's] like, 'If they ever turn against each other they can use that to their advantage.'"

Maria: "He probably means they could just climb back down to escape."

Here, Kay interpreted the importance the student was placing on choice, but Jack questioned whether the student understood why it was an important idea. Maria interpreted the student's idea about why climbing trees was advantageous to the snake. The point of this snippet is not to argue that the candidates were interpreting the students' idea correctly. The point is that the candidates were focused on trying to understand the student's unconventional idea and truly attending to his meaning—with little scaffolding from D nor the participation of Alex and other participants who had dominated the earlier conversations about student thinking.

In the next section, we discuss some of the differences that we saw among individual candidates. We describe Alex in more detail, as he was the most active participant, and we describe Maria as representative of some of the quieter participants who began to participate more over time. In addition, we discuss the three candidates who came in the second semester to show how they took up the practices of the group.

Differences among candidates.

As we described, throughout the discussions, Alex continued to identify examples of student thinking himself and to provide interpretations of others' examples to support evaluations. In some cases, he asked other candidates to support their statements with references to the transcripts or student work, asking several times "Where is that?" or "Where do you see that?"—comments that were coded as attention to tools. Both inside and outside of class, Alex commented on how his work as a lawyer helped him to understand the practice of attending to student thinking. He related the practices in the pedagogy course to "direct examination" where an attorney gathers evidence, as opposed to "cross-examination," where the goal is to challenge a witness' testimony.

Maria was one of the candidates who participated differently than Alex at the beginning. In the first two discussions, she spoke very little. By the third discussion, however, Maria was participating and attending to students' ideas. For example, as shown above, she brought up the students' idea about trees absorbing water, interpreted that the students were relating the wood (boards) mentioned in the poem, and evaluated it as a "positive thing."

Maria: "A positive thing I noticed, um, was they understood that wood absorbs the water. Like that was very visual for them because then they, in 170, they relate that to the plant and, like, a tree, and how the tree absorbs water."

Of the three candidates who came in the second semester, two (Steve and Kay) began to participate in practices of identifying, interpreting, and evaluating students' ideas right away. In the discussion below, candidates were discussing Joanna's curling video[3], in which Joanna showed students a video of the sport, and asked them to explain what was going on. Candidates were talking about another student's idea, when Jack changed the subject.

Jack: I was thinking back earlier when a student mentioned the Zamboni—how it smooths out the ice.

D: Right, so what about that Zamboni thing?

Jack: Well he's trying to explain how it gets smoother like when they're sweeping it, it kind of smoothes it off, and he sees that stuff get faster once its smooth, and so he's thinking that he's doing the same thing, by doing the same thing as the Zamboni.

Ryan: Yea, I didn't know that students know what a Zamboni does. They know that it makes it smoother but they don't know how.

Alex: Well, I mean it says in line 11, and it's in parenthesis, so it may not be exactly what he says, but he says wipes the frost off the...

Steve: Ok and I mean so Logan has an idea of that's at least what the Zamboni's doing; it's wiping frost off the ice. I think he's got a picture of like smooth hard ice and like fluffy frost that's getting wiped off so you get like a harder surface, flatter surface.

When Jack brought up the new student idea about the Zamboni, Ryan generalized that the students did not understand what it does. When Alex identified what the student said, Steve interpreted the student's idea specifically and how it provided evidence that he had an idea about what the Zamboni does. In the previous section, we also showed Kay making specific interpretations, which she did throughout the remaining discussions.

Unlike Steve and Kay, the third new candidate Terry took longer to participate in drawing specific interpretations. While Steve and Kay offered specific interpretations of students' ideas from the very first sample they saw, Terry spoke very little at first and did not provide any specific interpretations when she did. Thus, like the group that began in the summer semester, the newcomers were a mix of people who participated in practices of attending to student thinking

[3] In curling, athletes push a large stone across ice to a target, "sweeping" the ice in front of them to influence the stone's direction and speed.

immediately and others who began to participate more gradually.

Conclusions and Future Study

This work contributes to a growing understanding of novice teachers' tendencies to attend to the substance of student thinking and provides insight into how their practices of doing so develop and change over time. We show evidence that novice teachers can identify, interpret, and evaluate the substance of student thinking when they participate in pedagogy courses designed to draw attention to this topic. Most of the teacher candidates attended to student thinking from the beginning of the pedagogy course sequence. Additionally, the candidates became more adept at drawing specific interpretations of student thinking and using these interpretations to warrant general claims and evaluations of student understanding.

Some of our candidates were particularly adept at attending to student thinking. Throughout the discussions, Alex identified examples of student thinking, interpreted students' meaning, and commented on interpretations of other candidates' examples to support evaluations. We describe Alex as one of the candidates who took readily to practices of attending to student thinking. We suggest that Alex's experience as a lawyer helped to prepare him to attend to student thinking. We argue that experience in other settings can support new teachers' abilities to attend to student thinking; these experiences serve as resources that are activated in the pedagogy courses. This finding supports calls for recruitment of people from other careers into science teaching (Singer, 2009). As the example of Alex suggests, however, career switchers from a variety of fields outside of scientific practice, including law, policy, and journalism, can be valuable additions to the field assuming that they have sufficient background in science. Obviously, the one example of Alex does not make a strong claim for the productiveness of career switchers' experience. Alex is an unusually quick and articulate thinker, and there is surely considerable variation among career switchers, as there is among all people. However, we raise this issue to direct focus to the ways in which participation in practices outside of science and science education can contribute to an individual's tendencies to attend to thinking. Identifying Alex as someone who is very good at this has also been productive for further study. We are continuing to study Alex's classroom, to see if and how his tendency to attend to student thinking in the pedagogy course translates into his classroom practice (Gillespie, Richards, & Levin, 2010)

While some people may come to science teaching prepared with abundant productive resources for learning to attend to student thinking, this is not to suggest that other candidates lack resources to attend to student thinking. Our data from this study support the presence of resources to attend to the substance of student thinking. As we demonstrated above, even though Maria participated very little early on, she was attending to student thinking by the third discussion. Everyone has experience attending to others' thinking in everyday conversation—listening to others' ideas and interpreting their meaning. The greater issue is whether candidates frame the discussions about teaching practice as practices of attending to student thinking. That is, understanding that "what's going on" is that the group is primarily discussing and interpreting students' ideas and not focusing on the actions of the teacher or the nature of the activity.

We suggest that the framing of teaching in terms of attending to student thinking, while D explicitly facilitated it, was supported collectively through interaction among the participants in the group. Some of the candidates entered into the conversations very quickly and helped to support the framing that D was trying to establish. Over time, D's voice became less prominent as candidates directed each other to the transcripts and student work and pushed each other to articulate the specific evidence in student thinking that warranted claims of students' reasoning and understanding. The spirit of these exchanges continued into the third semester of the program, where candidates presented samples of student thinking from their own classrooms. These findings have implications for science teacher education. As others have shown, proper facilitation is necessary to draw attention to student thinking (Sherin & van Es, 2005). The role of the facilitator is both to encourage candidates to attend to student thinking and to support a collective framing of the activity by drawing candidates' attention to the tools and to the norms of discussing and challenging each others' interpretations.

Our findings also suggest productive avenues for further research. As we noted, there were differences in the ways that individual candidates attended to student thinking. Some, like Alex, offered substantive interpretations of students' ideas from the very beginning. Others were less likely to do so at first, but did so more as they began to participate more and saw the practices modeled by other candidates. We are now examining candidates' practices of attending to the substance of student thinking while they are teaching in their own classrooms, where they must listen to student ideas in real time while trying to manage other facets of the classroom and the curriculum. We have followed several candidates into the classroom, and are continuing to follow them to better understand how and when teachers elicit, attend to, and respond to the substance of student thinking while teaching science.

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